Simulation of MEMS for the Next Generation Space Telescope

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Summary

The NASA Goddard Space Flight Center (GSFC) is developing optical micro-electromechanical system (MEMS) components for potential application in Next Generation Space Telescope (NGST) science instruments. In this work, we present an overview of the electro-mechanical simulation of three MEMS components for NGST, which include a reflective micro-mirror array and transmissive microshutter array for aperture control for a near infrared (NIR) multi-object spectrometer and a large aperture MEMS Fabry-Perot tunable filter for a NIR wide field camera. In all cases the device must operate at cryogenic temperatures with low power consumption and low, CMOS compatible, voltages.

The goal of our simulation efforts is to adequately predict both the performance and the reliability of the devices during ground handling, launch, and operation to prevent failures late in the development process and during flight. This goal requires detailed modeling and validation of complex electro-thermal-mechanical interactions and very large non-linear deformations, often involving surface contact. Various parameters such as spatial dimensions and device response are often difficult to measure reliably at these small scales. In addition, these devices are fabricated from a wide variety of materials including surface micro-machined aluminum, reactive ion etched (RIE) silicon nitride, and deep reactive ion etched (DRIE) bulk single crystal silicon. The above broad set of conditions combine to be a formidable challenge for space flight qualification analysis. These simulations represent NASA/GSFC's first attempts at implementing a comprehensive strategy to address complex MEMS structures.

Next Generation Space Telescope (NGST)

NGST is a key part of the NASA Origins Program. Mission details include:

- 6.5 m primary mirror
- 0.6-27 µm wavelength range
- 2009 launch
- 5 year life (10 year goal)
- Passively cooled to <50K
- L2 orbit
- 3 core instruments:
  - 0.6-5 µm camera
  - 1-5 µm multi-object spectrometer
  - 5-27 µm camera/spectrometer

Two baseline instruments include MEMS components in the optical design. In particular, the 1-5 µm Multi-Object Spectrometer (MOS) requires an actively controlled mask at the focal plane that naturally calls for a MEMS solution. The baseline 0.6-5 µm camera includes a large aperture Fabry-Perot tunable filter, which can greatly benefit from a device based on MEMS actuation and fabrication techniques.

Electromechanical Simulation

Goals
- Predict performance
- Predict reliability
- Validate models

Challenges
- Large non-linear deformations
- Complex surface contact
- Electro-mechanical interaction
- Severe thermal mismatch

Environment
- Ground handling
- Launch
- Space flight

Software Tools
- MSC/NASTRAN
- IntelliSuite
- ANSYS/Multiphysics
- In-house code

References

Micro-shutters:
- http://bennet.gsfc.nasa.gov/ms_webpage/ms_animation.html

Micro-mirrors:
- http://repentium.gsfc.nasa.gov/~dsb/718etc.html

MEMS Fabry-Perot:
- http://analyst.gsfc.nasa.gov/jkuhn/papers/spie_fp_d000920.pdf

NASA/GSFC MEMS:
- http://mems.gsfc.nasa.gov

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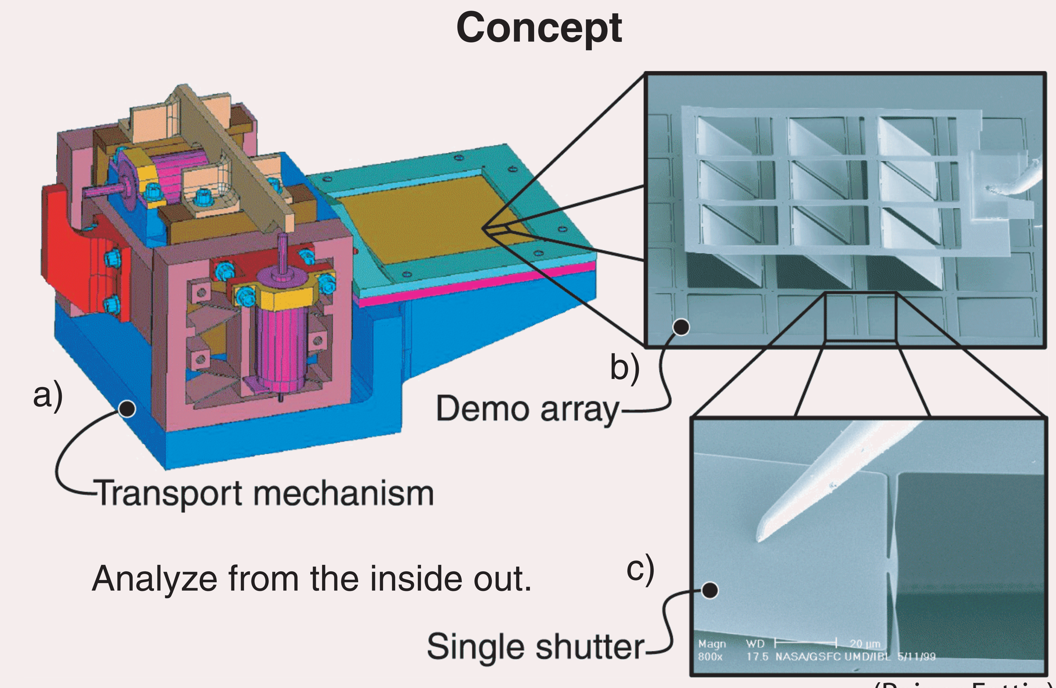
Micro-shutter Array

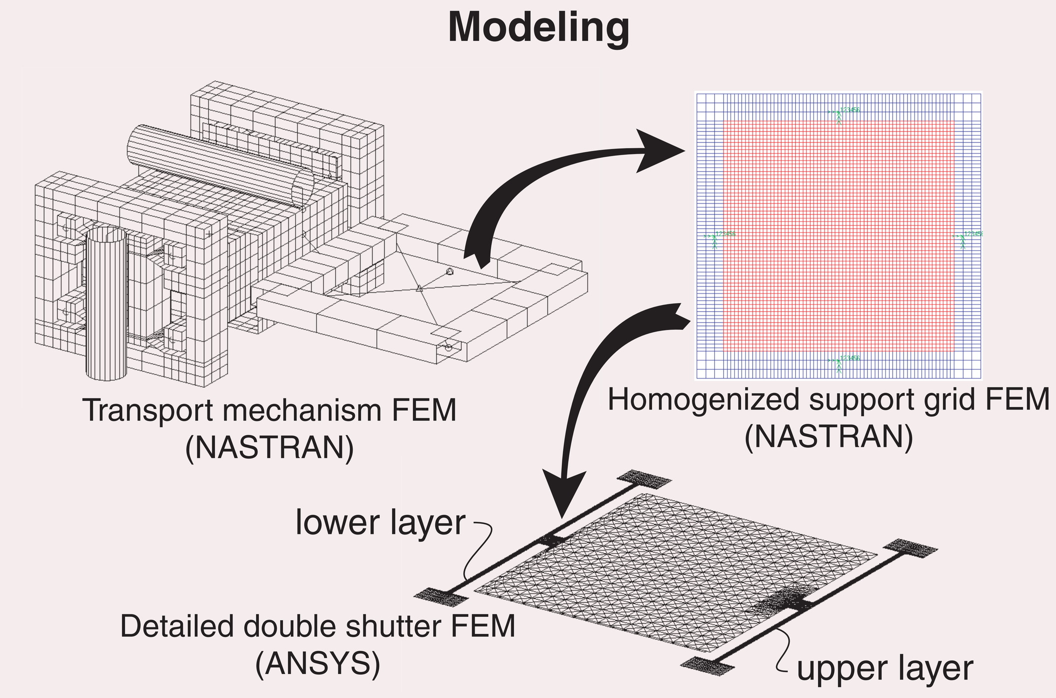
The micro-shutter array is a transmissive design for the NGST MOS, which offers minimal diffraction, resulting in the highest possible contrast. The concept is centered on DRIE of a silicon support structure, and RIE of 0.5 µm thick silicon nitride shutters suspended from torsional flexure hinges.

Concept



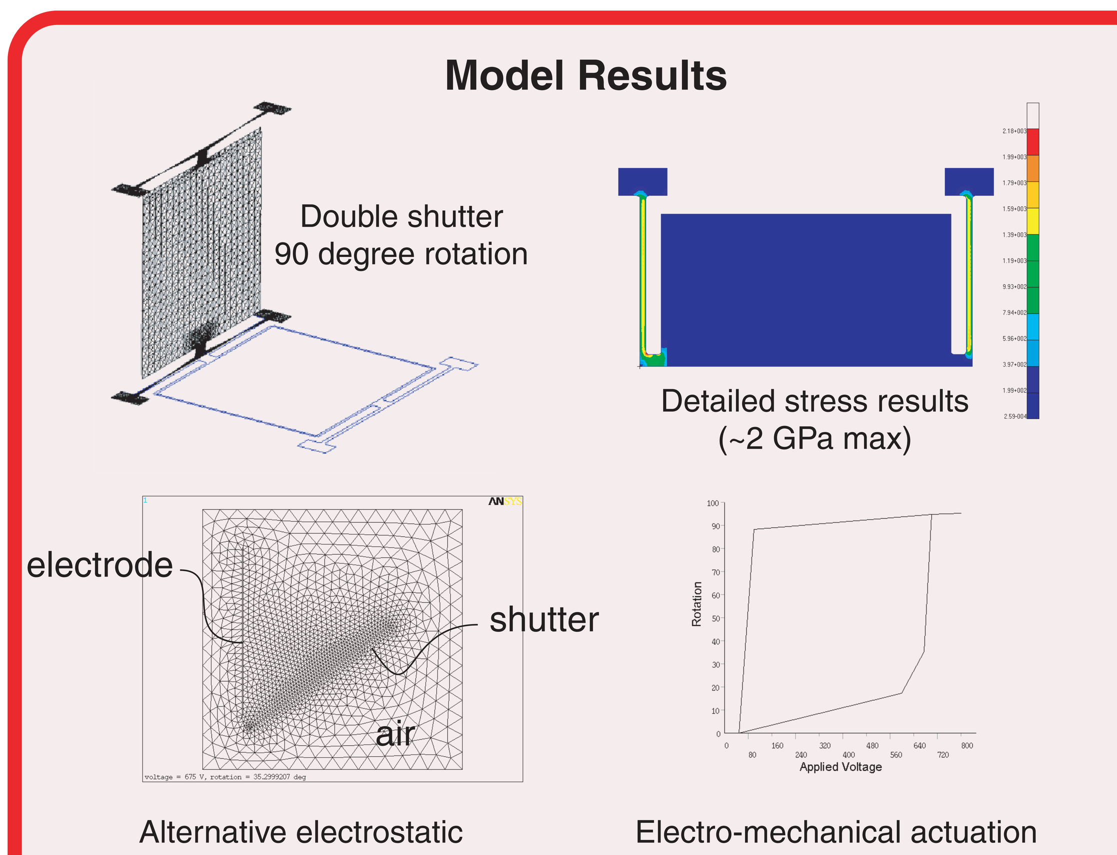
The double-shutter concept is comprised of three distinct length scales of the a) macro-scopic transport mechanism, b) support grid, and c) micro-shutters.

Modeling



Multi-scale homogenization is used to simulate each length scale. Detailed analysis of the micro-shutters is used to determine loads propagated up-ward and visa-versa.

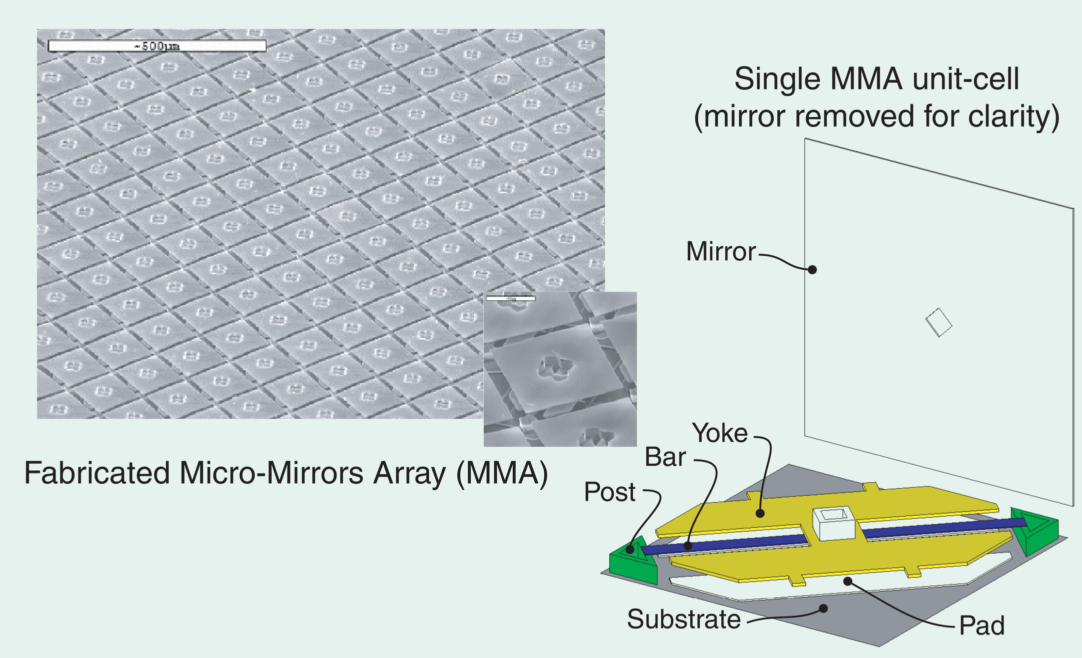
Model Results



Micro-mirror Array

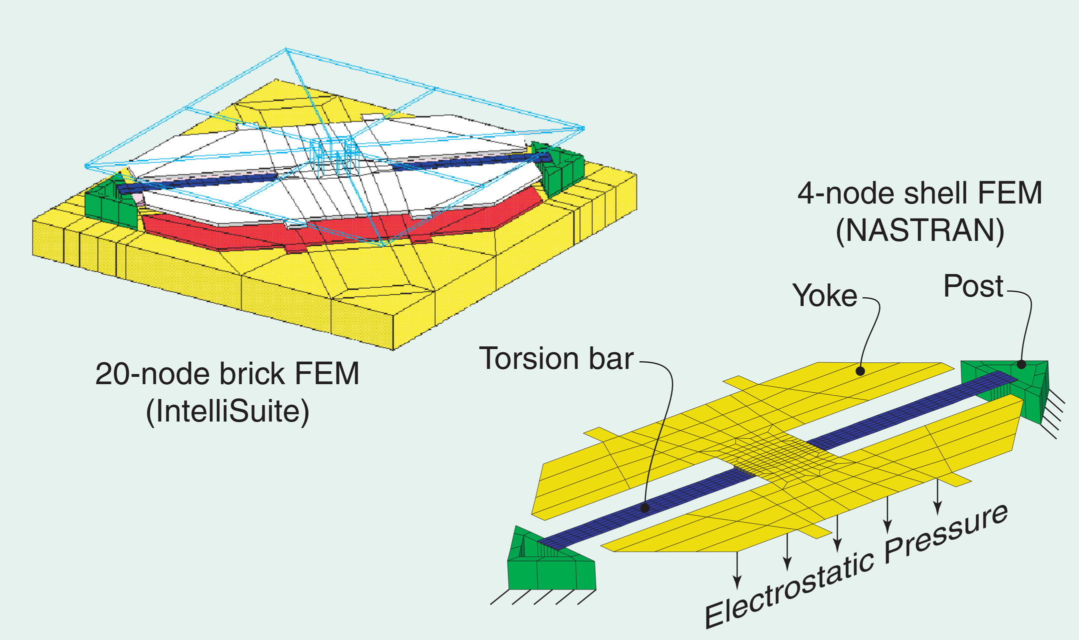
The micro-mirror array is a reflective design for the NGST MOS, which offers improved manufacturability and strong CMOS compatibility. The micro-mirrors are fabricated by surface micro-machining of aluminum.

Concept



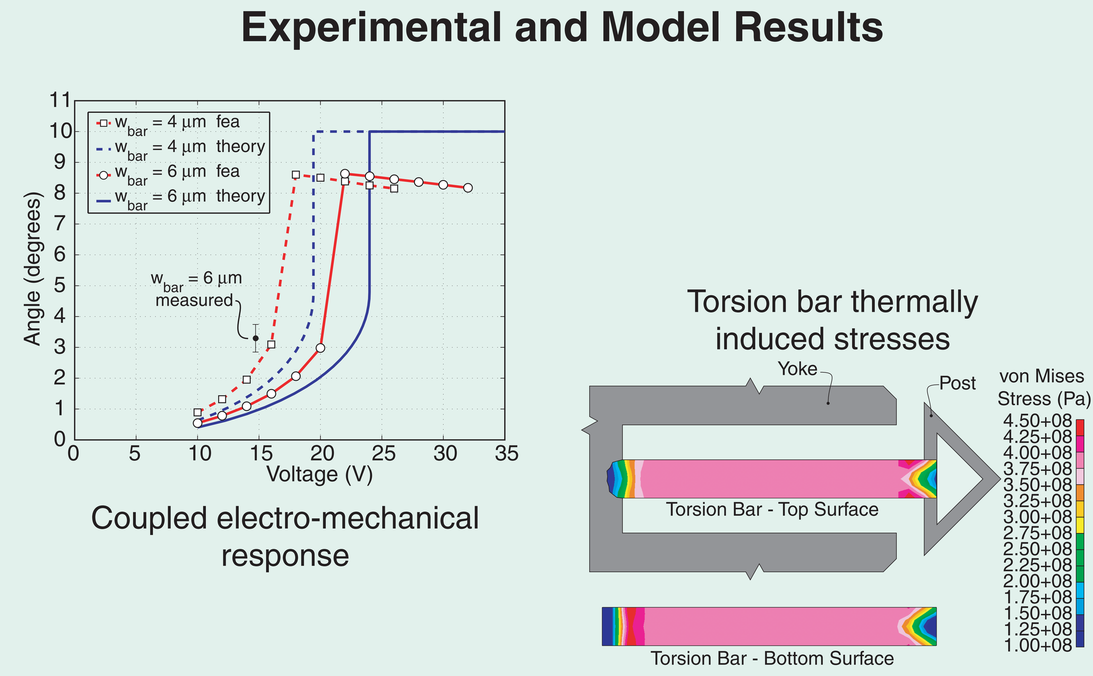
The tiltable aluminum micro-mirror design is comprised of a yoke suspended above two capacitance pads. An applied voltage induces bi-stable +/- 10 degree rotations.

Modeling



Both closed form and numerical techniques are used to predict the coupled electro-mechanical and thermal responses.

Experimental and Model Results

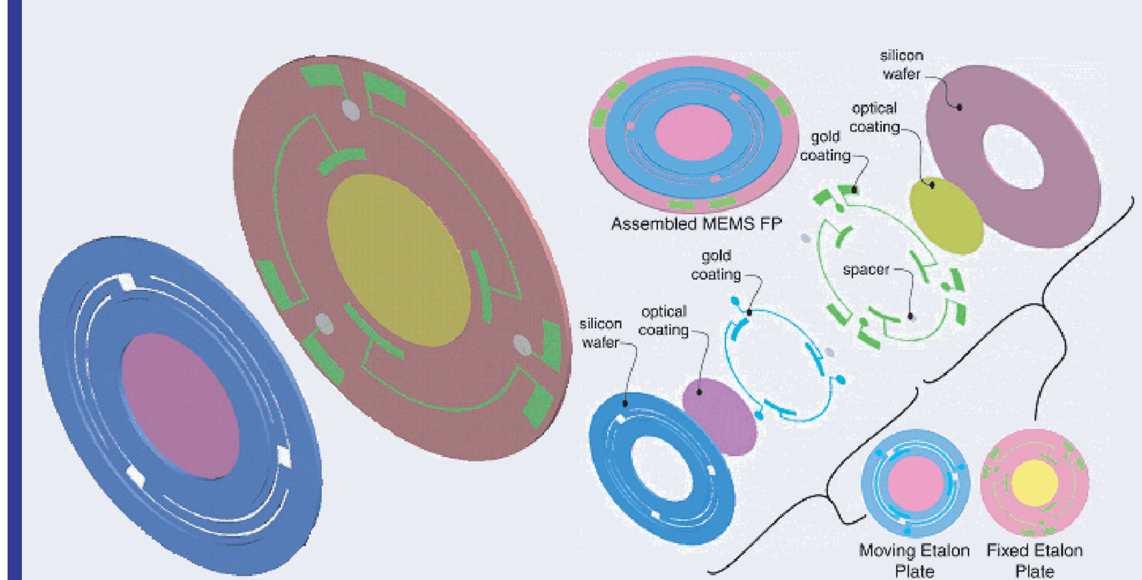


For this particular geometry the electro-mechanical response is strongly affected by vertical deflection of the torsion bars. The torsion bars may yield locally due to thermally induced loads.

MEMS Fabry-Perot

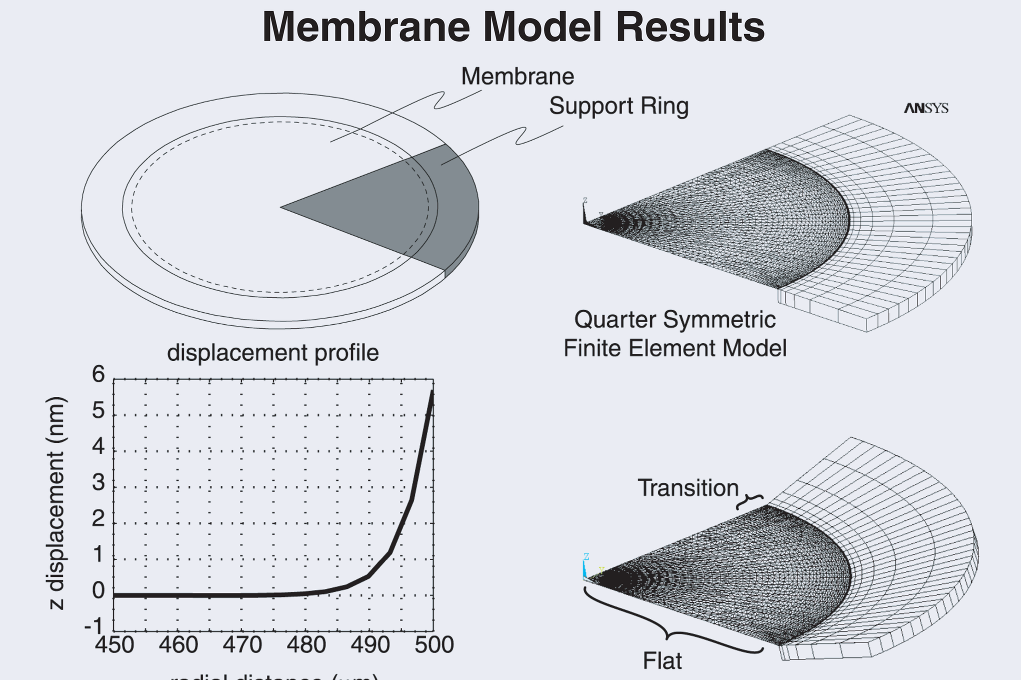
The MEMS Fabry-Perot is a large aperture tunable interference filter for the NGST NIR camera. The Fabry-Perot etalon plates are comprised of optical coatings suspended in drumhead tension to achieve flatness, and electrostatically actuated for tuning capability.

Concept



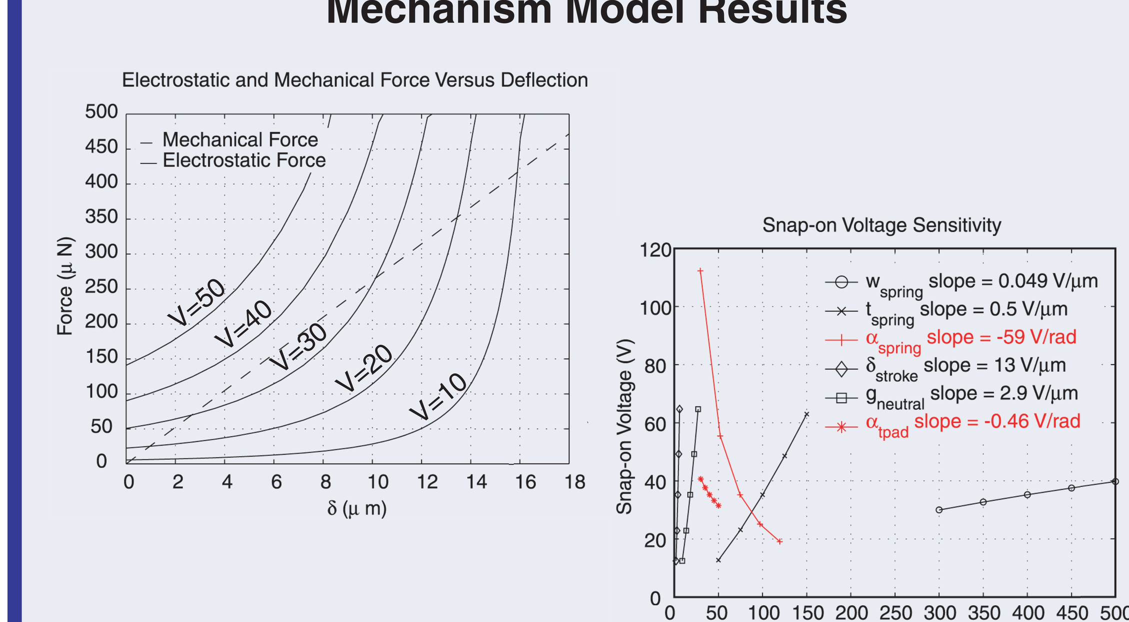
The electrostatically actuated MEMS Fabry-Perot tunable filter is comprised of two sub-assemblies fabricated from silicon wafers. The optical coatings are held in drumhead tension to meet stringent flatness requirements.

Membrane Model Results



Membrane model consisting of a pre-stressed membrane suspended from a silicon support ring.

Mechanism Model Results



Quasi-static mechanical response of the capacitor/spring actuation mechanism, and detailed parameter studies based on closed form solutions.

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